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Procedia Engineering 121 (2015) 1887 – 1893

Procedia Engineering

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9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Case Study of Space Cooling and Heating Energy Demand of a High-speed Railway Station in China

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Abstract

As a new type of large-scale public building, high-speed railway stations are developing fast throughout China. In general, most of the newly built stations have large, tall and open space like waiting hall and ticketing lobby, with large area of glass curtain wall or skylight. Such features may contribute to higher energy demand of the stations, especially for HVAC system. In this paper, a medium-size high speed railway station in South China is taken as an example to study the HVAC load characteristics for such buildings. Based on measured data and relevant information, and with the help of simulation tool DeST, cooling and heating load of the station are calculated and broken down into several major parts, including fresh air load, solar radiation, internal heat and building envelop. Main features are identified for the whole station and its major spaces, and then corresponding energy saving approaches are proposed.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords: Energy demand; High-speed railway station; Infiltration; Large spac; Solar radiation

1. Introduction

With the fast development of China, building energy consumption has become a hot topic. Nowadays, buildings account for more than 20% of China's total primary energy consumption, and further in depth, more than a quarter of the building energy is consumed by public buildings, especially large scale public buildings [1]. Meanwhile, railway construction is experiencing a high-pace development in China. According to the Medium and Long-term Development Plan of Chinese Railway, the total operating length of domestic railway will exceed 100,000 km at the

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Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.09.171

end of 2020. Meanwhile, more than one thousand rail-way stations will be built or reconstructed during this time period. In 2010~2011, the National Investigation Team of Energy Consumption for Large Railway Stations [2] conducted a large survey about the energy consumption of a series of railway stations across the country, and the overall energy use status was summarized at macro level. Besides, field test and investigation was conducted for some typical stations and some typical issues were realized for such buildings [3-6].

Among all kinds of railway station, high-speed railway stations (HSRS) built in recent years are drawing more and more attention. Different from other types of building or traditional railway stations, HSRS usually have large, tall and open spaces like waiting hall and ticket lobby, with large area of glass curtain wall or skylight, and have high density of passengers. Such features may probably contribute to higher energy demand of the stations, especially for HVAC system. Specifically, space cooling and heating load may be substantially influenced by the internal heat caused by high density of passengers and equipment, the solar radiation passing through the glass curtain wall or skylight, and the large amounts of air infiltration through the open doors at the entrances and exits.

Since HVAC is the largest consumer in public buildings, and cooling/heating load is the primary energy demand for HVAC system, the first step of energy saving for HSRS is to get a clear knowledge about the characteristics of space cooling and heating load, identify dominant factors and make sure which parts should be emphasized.

In this field, some efforts have been done during the past few years. Some researchers [7,8] tried to study the relationship between HVAC energy demand and factors like window-wall ratio or heat transfer coefficient of building envelop, in order to propose energy saving suggestions for the design of new stations. However, such researches are aimed for the optimization design, instead of energy saving for existing stations. And most of these researches merely discuss total energy demand of a station, while the formation of the total load and the proportion for each part remain unclear. Besides, current researches mainly focus on large space like waiting hall, lacking the comparative analysis between different spaces in a station.

Therefore, this study intends to focus on HVAC load of HSRS and its major contributors, including fresh air load, internal heat, solar radiation and building envelop load. A medium-size HSRS in South China is taken as an example to study the load feature and pattern, involving different spaces of the station, and to identify dominant factors and corresponding approaches to energy saving for HSRS.

2. Methods

This section gives a brief introduction of the case study HSRS, including its basic information and energy consumption status, and then describes the model for HVAC load simulation.

2.1. Description of the case station

The HSRS selected for case study is located in Hunan Province in South China. Built in 2009, the station has a total floor area of about 12,000 m2, of which 7,628 m2 is air conditioned. As shown in Figure 1, besides normal spaces like offices and equipment rooms, the station has a large and tall waiting room in the middle of the building, a tall ticket lobby in the northeast corner, an outbound channel in the south. The waiting room and ticket lobby are about 16.4m in height, while the other parts are normally divided into three stories.

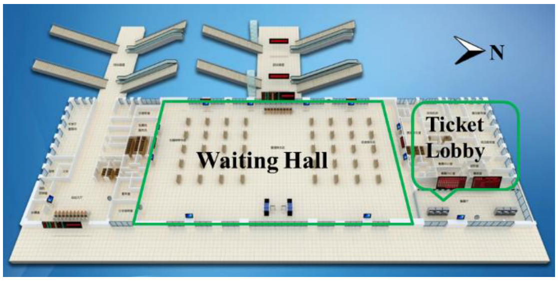

Fig.1. Sketch map of the case study HSRS

2.2. Energy consumption status

According to the energy consumption records of this station, about 306 kWh/m2 electricity was consumed in 2012, and the monthly energy consumption in 2012 is shown in Figure 2. It can be implied from the monthly trend that HVAC system operates from May to September for space cooling and operates from November to March for space heating. Besides, based on the energy monitoring system, the total energy of 2013/5~2013/8 is broken down into several major end-uses as shown in Figure 3. It is obvious that HVAC system consumes half of the total energy during summer, indicating priority should be given to HVAC in terms of energy saving. Due to the lack of monitoring points, some end-uses cannot be separated from each other. Thus in Figure 3, the large end-use, Others, includes water supply and drainage, exhaust fan, data center, etc.

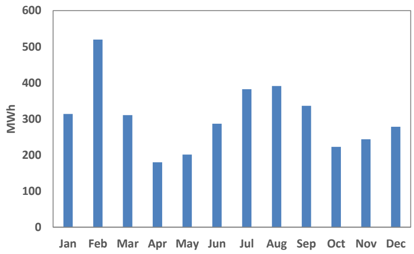

Fig. 2. Monthly energy consumption of the case station

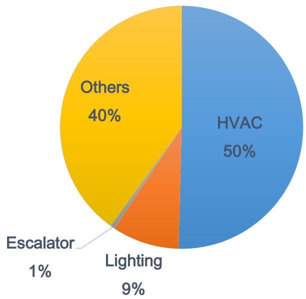

Fig. 3. Breakdown of total energy during 2013/5~2013/8

2.3. Model for energy demand simulation

In order to understand the main characteristics of the HVAC energy demand for such a HSRS, a simulation tool, DeST, developed by Tsinghua University, is adopted in this study to calculate the space cooling and heating load for each space. Based on the climate database provided by the software, hourly load throughout a year can be simulated.

Figure 4 shows the model of this station in DeST. According to the information acquired from design documents and the building manager, as well as the measured data from field test, key boundary conditions were determined and input to the building model. For instance, the passenger flow timetable comes from the station's ticketing system, while the envelop-related parameters come from design documents. Based on recorded energy data, cooling season is set to be May to September, while heating season is set to be November to March. As shown in Figure 4, the waiting hall is divided into two parts and conditioned by two air handling units respectively, in accordance with real condition. It is important to note that, besides the required amount of fresh air induced by HVAC system, there exist large amounts of air infiltration in the waiting hall and ticket lobby in reality. Due to the frequent passenger movement, the doors of these spaces are always open. Therefore, based on measured data in field test and wind parameters provided by the climate database, a fixed ventilation rate of infiltration, about 0.7 per hour, is added to these large spaces in the simplified model. In terms of HVAC zoning, most of the spaces, including waiting hall, ticket lobby and some offices, are in the charge of centralized chiller or heat pump, while another 20% of the spaces, including special spaces like data center and kitchen, are conditioned by VRF or distributed AC. Therefore, only the centralized chiller-conditioned area is discussed for HVAC load in this study.

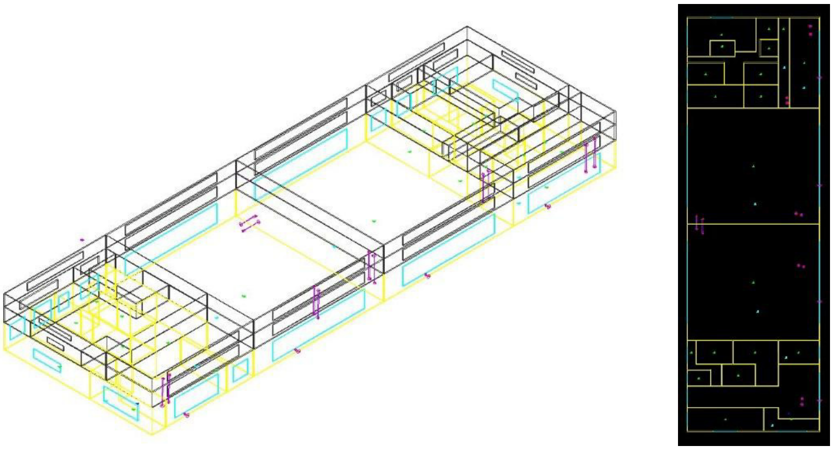

Fig. 4. Simulation model of the case station

3. Results

3.1. Model validation

Before analysis, the simulation results should be validated with the measured data from field test. Since the field test was conducted on Sep 11, the meteorological data of this day in the model were replaced with the measured data. As shown in Figure 5, during 10:00~18:00, the simulated cooling load is generally consistent with the measured value, and the error of the accumulative load in this time period is within 1%, indicating the validity of the model.

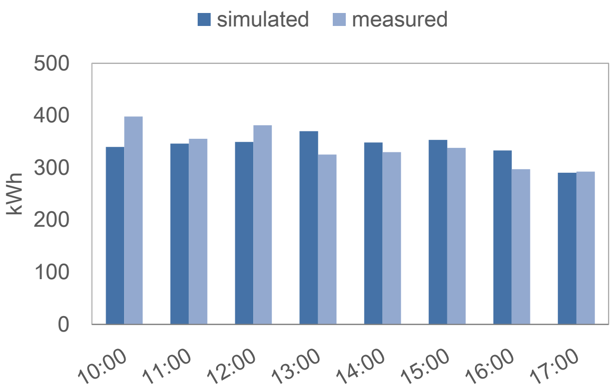

Fig. 5. Simulated vs. measured cooling load on a typical day

3.2. Cooling load analysis

In order to find the HVAC load characteristics, three typical days during cooling season are selected to conduct comparative analysis. Weather conditions of the three days are listed in Table 1, while the total cooling load of the chiller-conditioned area is divided into several major parts in Figure 6. Here, fresh air includes not only the required amounts of fresh air induced by HVAC system, but also redundant infiltration air through the open doors. Internal heat is produced by human bodies, lights and equipment, while another contributor is the solar radiation passing through the glass curtain walls. Building envelop here mainly refers to heat transfer, heat storage and discharge of building envelop, except the solar radiation through windows.

Table 1. Weather condition of three typical days in cooling season

	Jul 3 (weekday)	Jul 7 (weekend)	Sep 11 (weekday)
temperature (℃)	31	33	27
humidity （g/kg)	17	19	19
solar radiation intensity (W/m2)	411	395	96

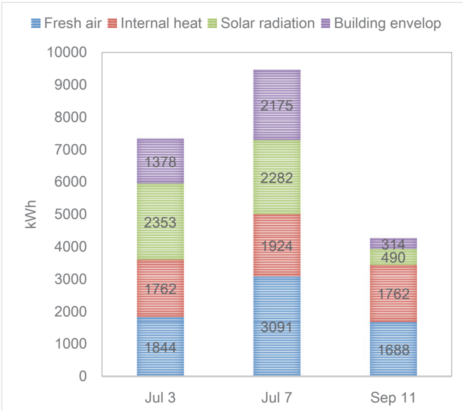

Fig.6. Cooling load on typical days

According to the simulation results, cooling load is substantially influenced by weather condition. Specifically, the higher outdoor air temperature and humidity on Jul 7 lead to its higher fresh air load and building envelop load. On the other hand, besides the low temperature on Sep 11, its low intensity of solar radiation also contributes to the lowest cooling load. In addition, apart from the weather dominated load, the internal heat load on Jul 7 is a little higher than the other two days, mainly because there are more passengers at weekend.

Further, in order to get an overview of the cooling load features, the breakdown of accumulative load of the cooling season is presented in Figure 7, not only for the whole building (referring in particular to the chiller-conditioned area), but also for each major space. It can be seen that the office area has quite a different load structure from the large spaces, ticket lobby and waiting hall. Firstly, solar radiation load is quite different between the two types of space, as a result of different window-wall ratios. Next, although the required fresh air standard for office area (30 m3/h per capita) is higher than the large spaces (10 m3/h per capita), there exist large amounts of infiltration in the large spaces, which is separated from required fresh air in Figure 7, and thus increasing the cooling load considerably. Besides, the reason for the higher building envelop load of office area seems to be complicated, since it has different envelop property from the large spaces, involving heat transfer, storage and discharge. Specifically, instead of shining directly into the room through glass curtain wall, solar radiation heat is stored by the external walls and discharged gradually into the office area. Meanwhile, the shape coefficient of office area is larger than the large spaces, which also contributes to its higher intensity (per floor area) of building envelop load. As for internal heat, there is no big difference between these spaces, mainly because the passenger flow volume of this medium-size station HSRS is not so large in reality, and there is not so much electric equipment in the large spaces.

On the whole, internal heat and solar radiation are the two largest contributors of total cooling load, accounting for about one third respectively. Besides, the permanently open doors of the large spaces also have significant influence on the total energy demand, since the waiting hall and ticket lobby account for 60% of the total load.

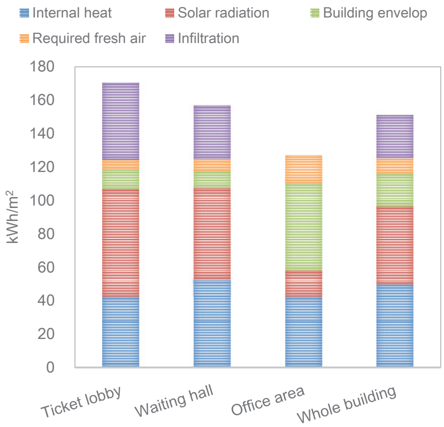

Fig. 7. Cooling load comparison between different spaces during cooling season

3.3. Heating load analysis

Similar to the cooling load analysis, heating load of different spaces throughout the heating season is shown in Figure 8. Contrary to cooling load, internal heat and solar radiation are favorable factors which can reduce energy demand. Particularly for the office area, owing to the heat storage of external walls, the envelop load is much lower than that of the large spaces, and thus its actual heating load is quite low. In terms of the whole building, 90% of the total heating load is caused by the waiting hall and ticket lobby, while building envelop and infiltration are the most important factor for heating load.

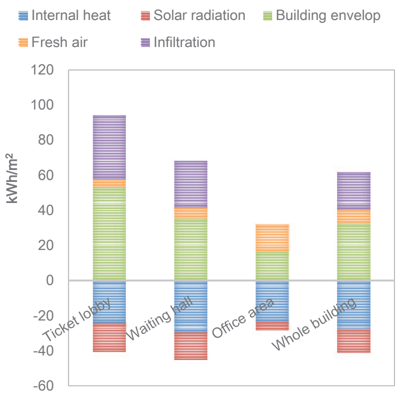

Fig. 8. Heating load comparison between different spaces during heating season

4. Discussion

According to the detailed analysis above, dominant factors of the station's cooling and heating load are identified respectively, and the discrepancy between different spaces are discussed. The results can shed some light on the designing of new HSRS in the future. However, for such an existing station, it is difficult and impractical to retrofit the building envelop, including the glass curtain wall. In reality, more efforts should be made to reduce the unwanted infiltration, which is a significant and adverse factor for both cooling and heating. For example, the air curtains at the entrances and exits of the large space might need improvement, and foyers might need installing, in order to prevent infiltration more effectively. Based on the simulation results, cooling load caused by infiltration accounts for about 12% of total cooling load of the whole station. Considering the real energy consumption data of the station, HVAC consumed about 980,000 kWh electricity during the summer in 2013. Therefore, about 60,000 kWh electricity per summer could be saved if the infiltration could be reduced by 50%. As for winter, due to the offset of different factors, the amount of infiltration load is similar to the total heating load. Therefore, if infiltration could be reduced by 50%, about 270,000 kWh electricity might be saved per winter. On the whole, the energy saving potential for reducing infiltration in this station is about 330,000 kWh electricity per year.

It should be noted that the model used in this study is a simplified one based on limited energy consumption data, design documents and field test on a typical summer day. Infiltration, as an important factor for HVAC load, is set to be fixed in this model, which may affect the accuracy of the simulation results, especially for winter. Since the ventilation rate of similar stations are even higher than the value in this study (Liu et al. 2011), and the stack effect is stronger in winter, there might exist more energy saving potential in respect to infiltration under real conditions.

5. Conclusion

In this study, a HSRS in South China is selected to analyze the HVAC load characteristics based on existing information, energy consumption data, field test and simulation. Generally, the station's total load is dominated by large spaces like waiting hall and ticket lobby, which have different features from office area. Specifically, solar radiation through glass curtain wall and air infiltration through the open doors have great effect on cooling and heating load, and thus making it sensitive to weather condition. Considering the applicability in fact, it is suggested that more emphasis be put on the reduction of air infiltration, where there exists considerable energy saving potential.

Acknowledgements

The authors appreciate the facility manager and other staff of the case study railway station, for providing relevant information and supporting our filed test.

References

[1] THUBERC (Tsinghua University Building Energy Research Centre), Annual report on China's building energy development, Tsinghua University, Beijing, 2015.
[2] National Investigation Team of Energy Consumption for Large Railway Stations, Analysis of the 2011 national investigation into the energy consumption of large railway stations, Railway Economics Research 109 (2012) 8-13.
[3] Y. Liu, C. Peng, D. Yan, Indoor environment status and energy saving design investigation of railway stations, HV&AC 41 (2011) 51-57.
[4] T. Luo, D. Yan, et al. Investigation and Optimum Design for Daylighting of Railway Station, China Illuminating Engineering Journal 23 (2012) 20-29.
[5] Y. Liu, G. Deng, et al. Current situation investigation and numerical simulation study of natural air infiltration in railway stations, HV&AC 42(12) (2012) 53-59.
[6] G. Song, Y. Liu, et al. Energy-using status and influence factors of railway stations, HV&AC 43 (2013) 85-90.
[7] J. Liu, B. Lin, et al. Case study – how could we optimize the energy-efficient design for an extra-large railway station with a comprehensive simulation? Building Simulation 2011- 12th Conference of International Building Performance Simulation Association, Sydney, Australia, 2011, pp. 498-505.
[8] Z. Wang, B. Lin, Y. Zhu, An Evaluation Method for Energy Efficiency Design of the Building Envelope of New Railway Stations, ISHVAC 2011- the 7th International Symposium on Heating, Ventilating and Air Conditioning, Shanghai, China, 2011, Vol. 1, pp. 171-176.